

Final Project Report

Summary of the Proposal (condensed from the application):

I propose to use Cerro Negro Volcano (CNV) in Nicaragua as an analog to help understand Mars' past environments and their astrobiological potential. Pristine volcanic deposits exist and possess very similar chemistry to the Martian meteorites and rocks on the planet's surface. Further, some of the CNV deposits are severely chemically altered by sulfur-bearing volcanic vapors. The fortunate aspect of this site is that it allows us to see the unaltered rock, the alteration processes operating, and the altered products. At the Mars landing site only the final product remains. Therefore we can use CNV to understand how the Mars rocks got to be the way they are and relate that to their potential habitability for life.

Actual Methods and Analyses:

Twelve days were spent in Nicaragua in early November, 2006 (GPS coords of Cerro Negro: 12° 30' 28"N; 86° 42' 08"W). During this time, I mapped the areas of interest, assessed the environment (pH, temperature, minerals, etc), and collected samples for analysis. I also visited several other sites that might be future areas of study. In the subsequent months, I used the remaining funds to analyze the samples. This included elemental and mineralogical analyses to study the chemical weathering pathways of these rocks similar in composition to those on Mars. Further, using outside resources, I added a new task to the project; namely a rudimentary assessment of the microbial population living in these hot, acidic environments that was completed with a colleague at Woods Hole Oceanographic Institute. Results were presented at the 7th *International Conference on Mars* held in Pasadena, CA, in July, 2007. I am also presenting the latest findings at the *Geological Society of America's Fall Meeting* in Denver, CO in late October of 2007 (references below).

The Lewis and Clark seed grant money has spurred on much additional research and current and pending grant money. In fact, I have current and pending grant awards directly related to continuation of this work. Thus, the Lewis and Clark seed money certainly planted a seed that is now blossoming into many fruitful branches. I greatly appreciate the chance to initiate this research and the initial funds have allowed a long-lived research project with direct relevance to assessing the potential for life beyond Earth.

Below I list the references for conference publications related to Cerro Negro as well as links to the full reports. I then provide an abridged version of the first conference report and include some pictures of the work and analysis. Please let me know if you require anything further and thank you very much for the opportunity to begin this exciting research project.

B. M. Hynek, K. L. Rogers, and T. M. McCollom (2007a) Cerro Negro, Nicaragua: A key mars analog environment for acid-sulfate weathering, *Seventh International Conference on Mars*, Pasadena, CA, abs. 3213.pdf

<http://www.lpi.usra.edu/meetings/7thmars2007/pdf/3213.pdf>

B. M. Hynek, K. L. Rogers, and T. M. McCollom (2007b) Cerro Negro Volcano, Nicaragua: An analog for geochemical processes on early mars and assessment of their potential for life, *Geological Society of America's Annual Meeting*, Denver, CO, abs. T91-013-4.

http://gsa.confex.com/gsa/2007AM/finalprogram/abstract_129449.htm

Abridged summary of Hynek et al. (2007a) referenced above:

CERRO NEGRO, NICARAGUA: A KEY MARS ANALOG ENVIRONMENT FOR ACID-SULFATE WEATHERING. B. M. Hynek¹, K L. Rogers², T. M. McCollom¹ Laboratory for Atmospheric and Space Physics, Univ. of Colorado, 392 UCB, Boulder, CO 80309 ²Woods Hole Oceanographic Institute, Woods Hole, MA. hynek@lasp.colorado.edu.

Background: The Mars Exploration Rover (MER) Opportunity has returned close-up images of exposed bedrock from Meridiani Planum, as well as data on their chemical and mineralogical composition (e.g., refs. 2, 4-5). The rocks reflect extensive acid-sulfate weathering of basalt early in Mars' history. Water chemistry is mostly inferred from the presence of the mineral jarosite at Meridiani Planum. This mineral forms in specific geochemical environments; namely low pH (~1-3) and oxidizing conditions. The MER Science Team has interpreted the bedrock to be a result of acid-sulfate weathering via predominately groundwater processes [2] while McCollom and Hynek [6] proposed that the weathering occurred in a high temperature volcanic environment. Either way, both models identify acid-sulfate weathering of basalt as a predominant process on early Mars.

A Terrestrial Analog at Cerro Negro Volcano, Nicaragua: We are currently exploring a terrestrial analog environment that can provide great insights regarding the habitability of early Mars in this type of setting. Cerro Negro ("Black Mountain"), Nicaragua, provides an ideal field laboratory to investigate the process of acid-sulfate weathering of Mars-like rocks.

Cerro Negro is one of the youngest and most active volcanoes on Earth. It has been constructed from 22 major eruptions beginning with its inception in 1850. Importantly, this youthful volcano has a basaltic chemistry that is remarkably similar to many of the Mars meteorites and unweathered basalts studied on Mars' surface. To date, most Mars analogs have a different parent rock lithology such as Yellowstone (granitic/rhyolitic) and the Atacama Desert (andesitic). The Rio Tinto site that is being studied as an analog for acidic, sulfur-rich environments on Mars formed by oxidative weathering of metal sulfide ore deposits within intercalated slate, quartzite, sandstone and limestone. This type of lithological setting has not been observed on Mars.

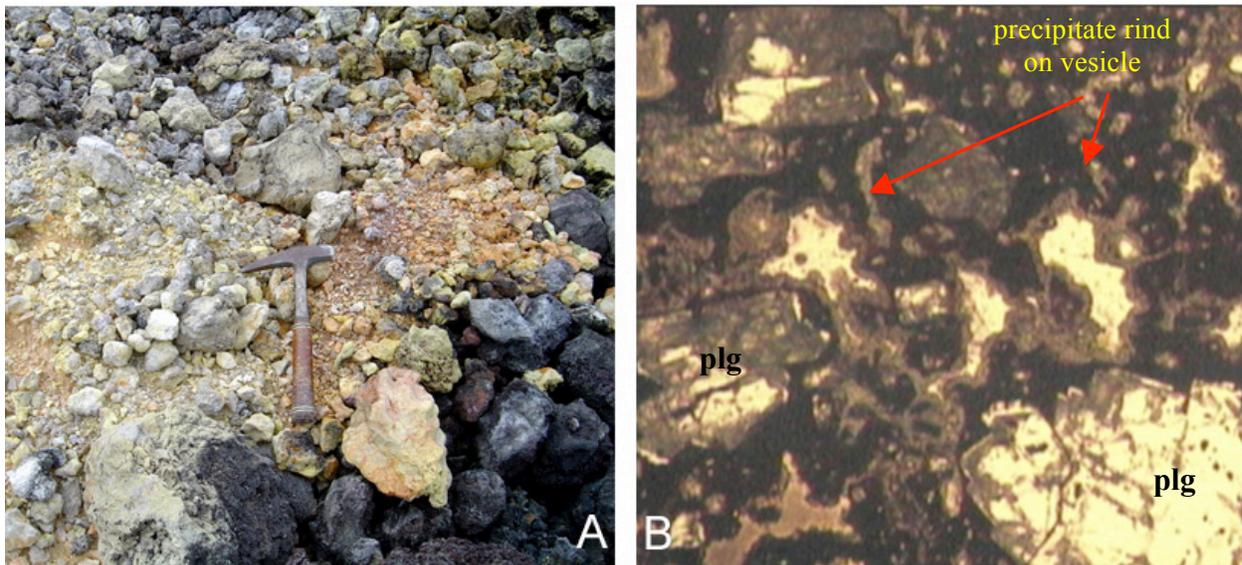
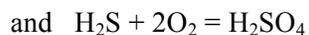
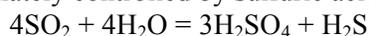


Figure 1. Cerro Negro context image (A) and thin section in visible light (B) taken from seven-year-old basalt that has undergone acid-sulfate weathering. Thin sections of pristine samples reveal basalt predominately composed of clinopyroxene, plagioclase (plg), and olivine phenocrysts in a dark matrix as well as opaques that likely represent Fe- and Mg-bearing materials. In (B), pervasive weathering of plagioclase crystals and precipitates rimming a vesicle are observed. Preliminary results from bulk rock analyses show that the altered samples contain abundant sulfates, iron hydroxides, minerals in the alunite/jarosite group, and up to 30 wt% SO₃.

Chemical Weathering at Cerro Negro Volcano, Nicaragua: At Cerro Negro, the basalts of Mars-like composition are undergoing extensive acid-sulfate weathering in a sulfur-rich fumarolic environment. The chemical weathering is predominately controlled by sulfuric acid that is produced by both



On a reconnaissance excursion in late 2006, lava and tephra hand samples were collected from several recent eruptions at Cerro Negro (i.e., 1999, 1995, and 1992). Samples from pristine to heavily altered basalts were collected. Standard laboratory techniques are being applied including XRD/XRF, thin-section petrography, and S analysis to study the acid-sulfate alteration pathways of these Mars-like basalts. The pristine basalts are characterized by relatively large phenocrysts of clinopyroxene, plagioclase, and olivine, along with opaques in a dark matrix (Figure 1). The rocks have similar elemental chemistry to those explored *in situ* on Mars as well as the SNC meteorites. This fact is crucial since the geochemical pathways and final assemblage of weathered products relies heavily on chemical composition of weathering fluids, which can be largely controlled by variations in host-rock lithology (i.e., ref. 16). In a few years, freshly erupted basalt can be converted into combinations of Ca-, Fe-, and Mg-sulfates, Fe-hydroxides, phyllosilicates, and free silica. Abundances of these groups can vary significantly. For example, ~80% free silica composed one of the most heavily weathered samples. These rocks have up to 30 wt% SO₃ equivalent, which is quite similar to the Meridiani Planum bedrocks studied by Opportunity [5] and inferred in other sulfate-bearing bedrock on Mars.

Geomicrobiological Analysis:

We are striving to establish the phylogenetic diversity of the microbial population at the Cerro Negro solfataria system. In addition to the rocks collected for mineralogical analysis discussed above, roughly ten sediment samples were collected within or in close proximity to active vents (Figure 2). We took care to sample the diversity present by sampling half a dozen different vent systems with significant variations in mineralogy (Figure 2). Ongoing culture-independent techniques are expanding our understanding of the geochemical parameters that constrain life in solfataria systems. This work, coupled with theoretical geochemical modeling of such environments, is aiding in the prediction of the biological potential for life in similar systems on early Mars. To date, we have extracted 16S rDNA and are in the process of assessing the environmental population. Understanding the microbial population and their energy sources will yield clues to the habitability of early Mars.



Figure 2. Context photo showing several large-scale fumaroles at Cerro Negro, Nicaragua. Differences in color relate to differing mineral assemblages and degrees of alteration. The arrow points to a person for scale.

Brian HYNEK, University of Colorado, Lewis and Clark Scholar, 2006-2007
MARS' ASTROBIOLOGY POTENTIAL FROM CERRO NEGRO VOLCANO, NICARAGUA

Future Plans and Funding:

The Lewis and Clark seed money has resulted in 2 conference papers (mentioned above) and two additional grant proposals. The first of which was a recent grant award from the University of Colorado to conduct laboratory experiments that replicate the Cerro Negro and early Mars environments.

Evaluating the geologic history of Meridiani Planum on Mars through laboratory experiments and modeling, University of Colorado's Innovative Seed Grant Program. Brian Hynek, Principal Investigator.

Additionally, I have submitted a proposal to NASA's 2007 Exobiology Program to continue work at Cerro Negro, with the main goals being to assess the microbial population around the volcano's vents, couple this with theoretical modeling, and then apply the results to environments on ancient Mars:

Cerro Negro, Nicaragua: An analog for assessing the potential for life on early Mars, NASA Exobiology, submitted September 20. Brian Hynek, Principal Investigator.